

# World Housing Encyclopedia

*A Resource on Construction in Earthquake Regions*



an initiative of  
Earthquake Engineering Research Institute (EERI) and  
International Association for Earthquake Engineering (IAEE)

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## HOUSING REPORT RC Moment Frame Building

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<b>Report#</b>	103
<b>Last Updated</b>	
<b>Country</b>	Algeria
<b>Author(s)</b>	Mohammed Farsi , Farah Lazzali , ,
<b>Reviewers</b>	Mauro Sassu,

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### Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John

## **General Information**

<b>Building Type:</b>	RC Moment Frame Building
<b>Country:</b>	Algeria
<b>Author(s):</b>	Mohammed Farsi Farah Lazzali
<b>Last Updated:</b>	
<b>Regions Where Found:</b>	<p>Buildings of this construction type can be found in northern Algeria, which is an area of high seismic activity. This construction constitutes about 60-70% of the total residential building stock. This type of housing construction is commonly found in suburban areas. A large part was built in the 1980s by their owners without any consideration to the requirements of the seismic code. This construction type is rarely found in densely populated urban areas; it is rather practiced in suburban areas where building lots are still available. In rural areas, the most common housing construction is tied stone masonry.</p>
<b>Summary:</b>	<p>This privately owned housing constitutes about 60 to 70% of the housing stock and is widespread throughout northern Algeria, the region of the country's highest seismic risk. Generally, these buildings are from 1 to 3 stories high. The ground floor is used for parking or for commercial purposes. The structural system consists of reinforced concrete frames with masonry infill walls made out of hollow brick tiles. The infill walls are usually provided in the residential part of the building (upper floors). Due to the limited amount of infill walls at the ground floor level, these buildings are characterized by soft-story behavior during earthquakes. These buildings have most often been built after the development of the 1981 Algerian seismic code. However, the seismic code is not enforced in private construction and most of the buildings have been built without seismic strengthening provisions and historically have been severely affected in Algerian earthquakes, including the May 21, 2003 Boumerdes earthquake. This report does not describe reinforced concrete frame buildings financed by public or private property</p>

developers and built according to the seismic code.

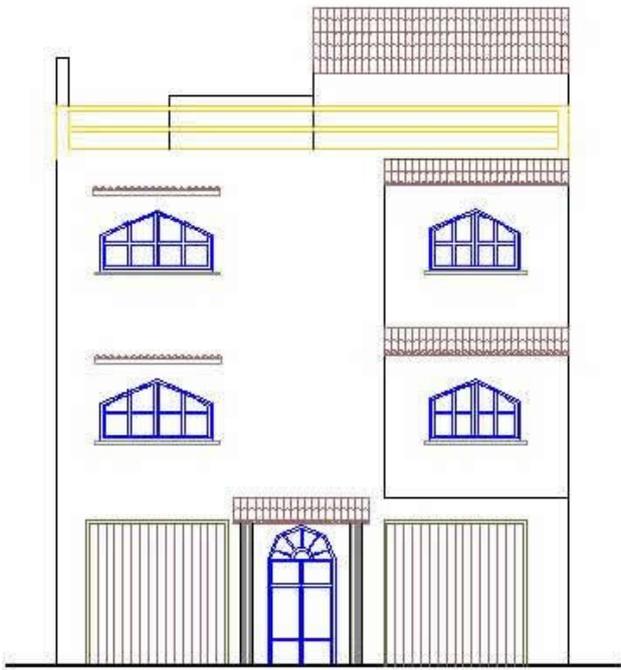
<b>Length of time practiced:</b>	25-60 years
<b>Still Practiced:</b>	Yes
<b>In practice as of:</b>	
<b>Building Occupancy:</b>	Single dwellingMixed residential/commercial
<b>Typical number of stories:</b>	3
<b>Terrain-Flat:</b>	Typically
<b>Terrain-Sloped:</b>	Never
<b>Comments:</b>	The construction of individual reinforced concrete frame houses has been practiced since 1980s. To solve the housing crisis in t

## Features

<b>Plan Shape</b>	Square, solidRectangular, solidL-shape
<b>Additional comments on plan shape</b>	
<b>Typical plan length (meters)</b>	15
<b>Typical plan width (meters)</b>	10
<b>Typical story height (meters)</b>	3-5
<b>Type of Structural System</b>	Structural Concrete: Moment Resisting Frame: Designed for gravity loads only, with URM infill walls
	The vertical load-resisting system is reinforced concrete moment resisting frame. RC frames (columns-beams) designed for gravity load only, with infilled masonry walls. The lateral load-resisting system is reinforced concrete moment resisting frame. These non-engineered reinforced concrete frames have been designed for gravity loads only. Typical column dimensions are 250 mm x 250 mm; in some cases, 300 mm x 300 mm columns have been used. Typical column reinforcement consists of 6 - 12 mm diameter bars or 4 - 14 mm bars. The ties typically consist of 8 mm bars at 200 mm spacing; the tie spacing remains unchanged even in the beam-column joint area. Typical beam dimensions are 250 mm width x 300 mm depth; in

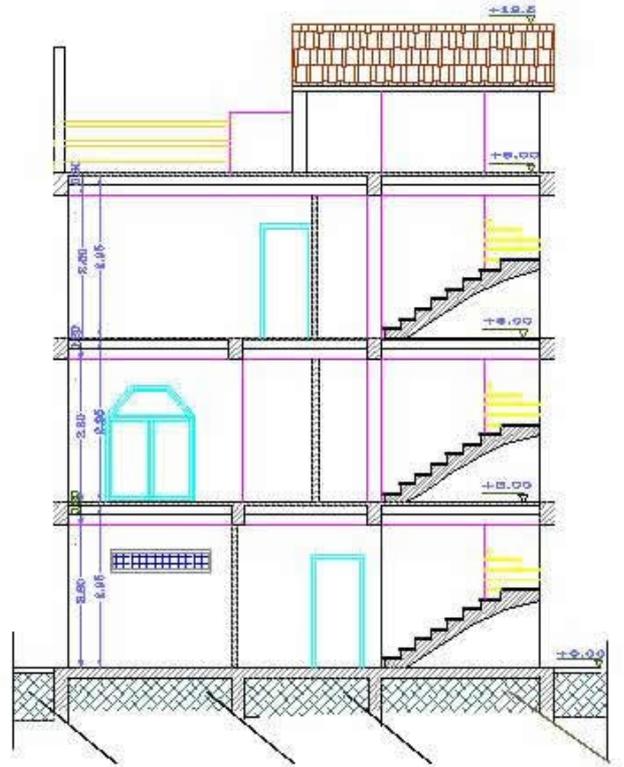
<p><b>Additional comments on structural system</b></p>	<p>some cases, 300 mm beam width is used to match column dimensions. Beams are usually reinforced with 6 bars of 12 mm or 14 mm diameter. The stirrups consist of 8 mm bars at 200 mm spacing; the spacing is constant over the beam span. Seismic detailing is not provided in the beam-column joint region; column and beam longitudinal reinforcement is generally continuous through the joints, however ties are not provided in the joint area. The frames are infilled with unreinforced hollow clay tile wall panels. These panels are not attached to the frames; the gap between the infills and the frame is filled with mortar. Floor slabs are of composite construction, consisting of precast reinforced concrete beams supporting hollow concrete blocks (160 mm thickness) topped with a 40 mm thick reinforced concrete slab, see Fig.7. The slab is reinforced with 8 mm reinforcement bars at 150 mm spacing. The overall thickness of the floor slab is 200 mm.</p>
<p><b>Gravity load-bearing &amp; lateral load-resisting systems</b></p>	<p>The moment-resisting frame in this building type has a very limited earthquake resistance.</p>
<p><b>Typical wall densities in direction 1</b></p>	<p>1-2%</p>
<p><b>Typical wall densities in direction 2</b></p>	<p>1-2%</p>
<p><b>Additional comments on typical wall densities</b></p>	<p>The building typically has 1 to 3 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical plan dimensions do not vary more than +/- 2 meters. The ground floor height is about 4-5 meters, whereas the floor height of the upper floors is around 3 meters. Span: The average distance between the columns is about 4 meters, but it can vary from 3 to 5 meters. The typical storey height in such buildings is 3 meters.</p>
<p><b>Wall Openings</b></p>	<p>A typical house has 6 to 10 windows per floor, with a total average size of 3.0 m<sup>2</sup>. The position of these openings is variable, but usually is approximately 0.8 to 1.0 m from the floor level in rooms and from 1.8 to 2.0 m in bathrooms.</p>
<p><b>Is it typical for buildings of this type to have common walls with adjacent buildings?</b></p>	<p>No</p> <p>Typical modifications include closing off the balconies and demolishing the interior walls to rearrange the apartments or to change the use</p>

<b>Modifications of buildings</b>	rearrange the apartments or to change the use. Often, additional stories are added without a building permit and without taking into account the load-bearing capacity of the structure.
<b>Type of Foundation</b>	Shallow Foundation: Reinforced concrete isolated footing
<b>Additional comments on foundation</b>	Common foundations are reinforced concrete isolated footings. This foundation type has been adopted without geotechnical study of the site and without the recommendation of civil engineers.
<b>Type of Floor System</b>	Other floor system
<b>Additional comments on floor system</b>	The floor/roof system is made with a precast joist system, hollow concrete blocks and a 40-50 mm thick cast-in-place slab.
<b>Type of Roof System</b>	Roof system, other
<b>Additional comments on roof system</b>	The floor/roof system is made with a precast joist system, hollow concrete blocks and a 40-50 mm thick cast-in-place slab.
<b>Additional comments section 2</b>	The seismic vulnerability in this building type is due to the fact that the ground floor is used for commercial purposes and the upper levels for residences. Sometimes heavy items are stored on the upper floors when the entire building is used for commercial activity. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. The only means of escape is the main entrance door; there is only one staircase in each building.



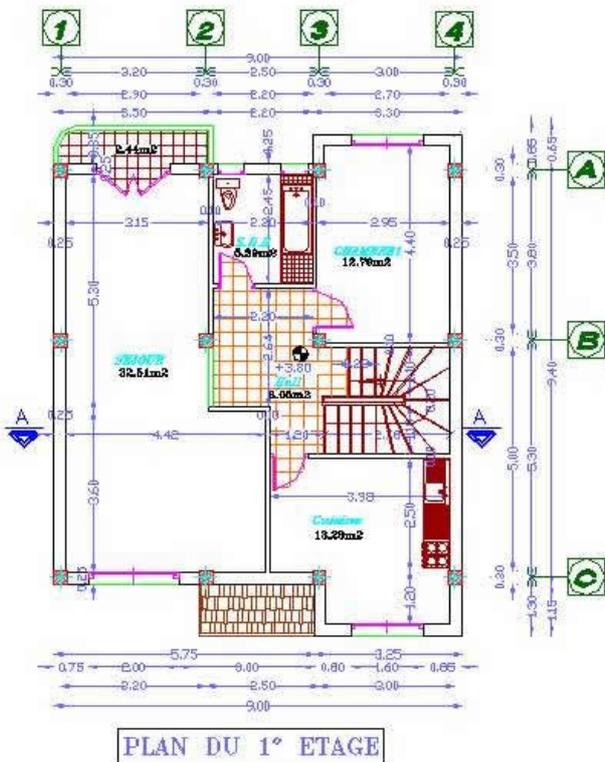
FACADE PRINCIPALE

*Facade view of a typical building*



COUPE A - A

*A typical vertical section through a building showing key load-bearing elements*



PLAN DU 1° ETAGE

*Plan of a typical building*



*Irregular RC moment frame building system.*

# Building Materials and Construction Process

## Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: Brick	Wall: 200 mm x 300 mm (block height x length) Thickness is variable: typical values are 50, 100, 150 and 200 mm
Foundations	Reinforced concrete	fe28=20 MPa (concrete) fe=400 MPa (steel yield strength) 1:2:4 (cement:sand:aggregate) The concrete compressive strength is often less than 20 MPa.
Floors	Reinforced concrete	fe28=20 MPa fe=400 MPa 1:2:4 The concrete compressive strength is often less than 20 MPa but is sufficient in comparison with the slab rigidity
Roof	Reinforced concrete	fe28=20 MPa fe=400 MPa 1:2:4 The concrete compressive strength is often less than 20 MPa but is sufficient in comparison with the slab rigidity
Other	Concrete	fe28=20 MPa fe=400 MPa 1:2:4 The concrete compressive strength is often less than 20 MPa.

## Design Process

<b>Who is involved with the design process?</b>	Architect
<b>Roles of those involved in the design process</b>	Generally, the architect who planned the house has a sufficient level of expertise, however, the houses are not designed for seismic events. The mason doing the construction does not have this expertise. The role of the architect is to design the building and to develop design drawings and architectural plans. Before 2003, Engineers do not play a role in the construction of these buildings because they are not involved by the owners and architects.

<p><b>Expertise of those involved in the design process</b></p>	<p>The expertise required for the design and construction of this type is available. Building designs were prepared by design institutes. The academic background of the designers is the same as for conventional construction. It is not required to have designers with high academic degrees e.g. M.Sc. and Ph.D. on the team. Construction of base isolated buildings and the approval of the designs were controlled by research institutes (State Experts) like any other new construction performed in accordance with the Building Code requirements.</p>
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**Construction Process**

<p><b>Who typically builds this construction type?</b></p>	<p>Owner</p>
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<p><b>Roles of those involved in the building process</b></p>	<p>This housing type is built by the owners themselves. They live in the house and very rarely rent it out. Often, after the owner obtains a building permit, (s)he hires a mason to build the house. The owner supplies the construction materials himself. Seldom are developers or contractors involved.</p>
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<p><b>Expertise of those involved in building process</b></p>	<p>The expertise required for the design and construction of this type is available. Building designs were prepared by design institutes. The academic background of the designers is the same as for conventional construction. It is not required to have designers with high academic degrees e.g. M.Sc. and Ph.D. on the team. Construction of base isolated buildings and the approval of the designs were controlled by research institutes (State Experts) like any other new construction performed in accordance with the Building Code requirements.</p>
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<p><b>Construction process and phasing</b></p>	<p>The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size. It often takes 6-7 years to complete individual buildings; frequently this is because of financing problems. Sometimes the completed building has undergone modification during the construction as compared to the original design.</p>
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<p><b>Construction issues</b></p>	<p>Inadequate design, weak concrete strength, poor quality of materials and construction.</p>
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**Building Codes and Standards**

<p><b>Is this construction type address by</b></p>	<p>Yes</p>
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<p><b>codes/standards?</b></p>	<p>This construction type is addressed by the codes/standards of the country. The codes/standards currently in force are RPA99 (Seismic Algerian Code 1999) and CBA93 (Reinforced Concrete Code). The year the first code/standard addressing this type of construction issued was 1981 (the first version of Algerian Seismic Code). The most recent code/standard addressing this construction type issued was CBA93 (Reinforced Concrete Code) was issued in 1993 and RPA99 (Algerian Seismic Code) was issued in 1999 and revised in 2003. Title of the code or standard: RPA99 (Seismic Algerian Code 1999) and CBA93 (Reinforced Concrete Code). Year the first code/standard addressing this type of construction issued: 1981 (the first Algerian Seismic Code) National building code, material codes and seismic codes/standards: RPA99 (Algerian Seismic Code), CBA1993 (National Building Code) When was the most recent code/standard addressing this construction type issued? CBA93 (Reinforced Concrete Code) was issued in 1993 and RPA99 (Algerian Seismic Code) was issued in 1999.</p>
<p><b>Applicable codes or standards</b></p>	<p>The enforcement of the building code for public buildings in Algeria is done by the Controle Technique de la Construction (CTC). After the architectural plans have been prepared, their conformity to the building codes (CBA93, RPA99, etc.) must be approved by the CTC. The approval is related to the phases of the construction and the quality of the building materials. However, code enforcement is not required by Planning Services for private housing. As a result, the construction can proceed with only architectural plans. There is no inspection or quality control enforced during the construction.</p>

## Building Permits and Development Control Rules

<p><b>Are building permits required?</b></p>	<p>Yes</p>
<p><b>Is this typically informal construction?</b></p>	<p>No</p>
<p><b>Is this construction typically authorized as per development control rules?</b></p>	<p>Yes</p>

This type of construction continues to be practiced

**Additional comments on building permits and development control rules**

in the present and is authorized by the regulations controlling development. However, after 2003 Boumerdes earthquake it is requirement that the work be performed in compliance with the rules of construction practice or seismic design. Building permit is required to build this housing type. Unfortunately, some of the construction is carried out informally.

**Building Maintenance and Condition**

**Typical problems associated with this type of construction**

The housing developments established generally surrounding large cities and in suburban areas, do not comply with the environmental and urban planning issues, in addition to the delay to make urban roads and wastewater disposal system.

**Who typically maintains buildings of this type?**

Owner(s)

**Additional comments on maintenance and building condition**

The maintenance is performed either by the owner.

**Construction Economics**

**Unit construction cost**

The unit construction cost is estimated to be 60,000-90,000 DA/m<sup>2</sup> (700-1100 \$US) (market rate is 1\$=83 DA). The number of work days required to complete the construction depends on the financing and the number of stories. If there is not a problem with the financing, one story can be completed within 8-12 months. For the typical three-story building, 2-3 years are required for completion.

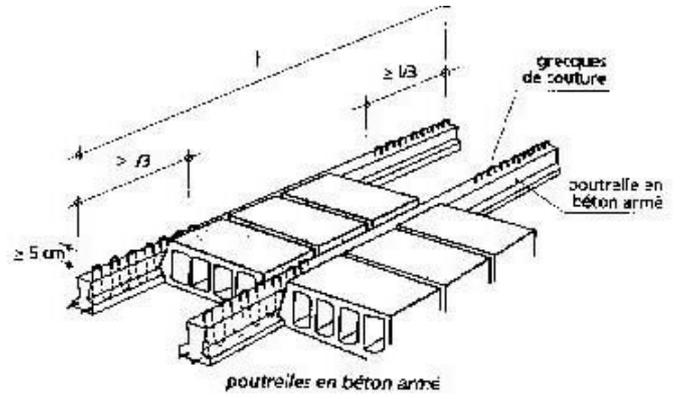
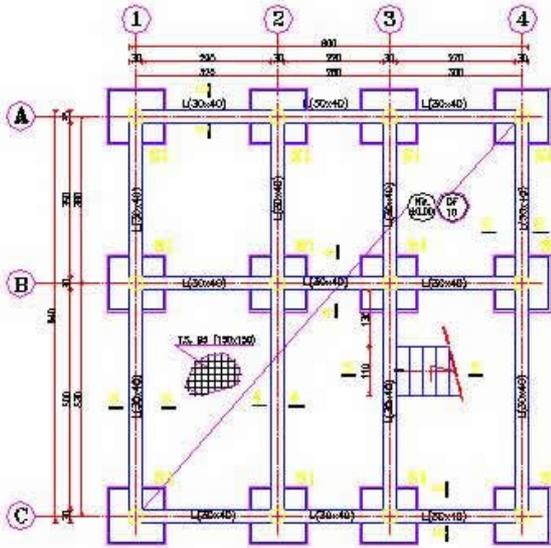
**Labor requirements**

Each housing unit in rural area takes around 8-12 man-months (counting skilled man-months only) for construction. Only one or two skilled artisans are used, while the remaining are unskilled workers.

**Additional comments section 3**

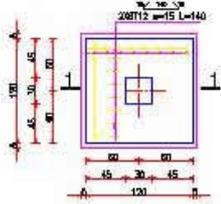
These buildings were constructed using the following construction materials:2. Exterior walls (2 layers); one layer is made using regular concrete and the other one is made of lightweight concrete (for the purpose of heat insulation).3. Interior walls are made of regular concrete.

COFFRAGE FERRAILLAGE FONDATIONS

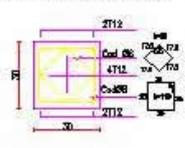


Typical floor slab construction

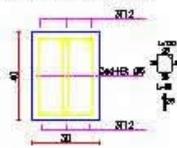
SEMELLE S1(120x120x30)



FERRAILLAGE POTEAUX



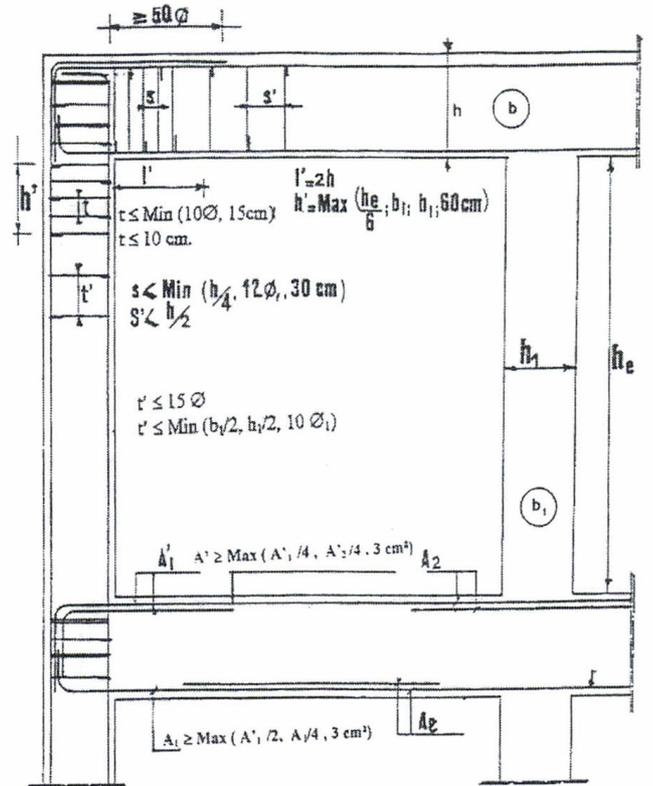
FERRAILLAGE POUTRES



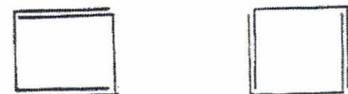
Foundation plan



Typical building under construction



Détail d'un cours d'armatures transversales de la zone nodale



2U superposés ( avec alternance dans l'orientation )

Earthquake-resistant provisions of

***theRPA99 related to RC frame construction***

**Socio-Economic Issues**

<b>Patterns of occupancy</b>	Each building typically has 1 housing unit(s). 1 units in each building. There is generally one housing unit (in each house or building). Sometimes this building contains one apartment on each floor when married sons live with their parents.
<b>Number of inhabitants in a typical building of this construction type during the day</b>	<5
<b>Number of inhabitants in a typical building of this construction type during the evening/night</b>	5-10
<b>Additional comments on number of inhabitants</b>	The number of persons living in one building depends on the social and economic status of the occupants. The number of occupants is smaller for families from higher economic levels. Usually, there are 6 to 8 family members living in the same building.
<b>Economic level of inhabitants</b>	Middle-income class High-income class (rich)
<b>Additional comments on economic level of inhabitants</b>	For most owners (who are generally of the intellectual class), the construction takes many years. Economic Level: For Middle Class the ratio of the Housing Unit Price to their Annual Income is 20:1. For Rich Class the ratio of the Housing Unit Price to their Annual Income is 6:1.
<b>Typical Source of Financing</b>	Owner financed Personal savings Small lending institutions/microfinance institutions
<b>Additional comments on financing</b>	This is a privately owned construction, that is, the construction is self-financed. The owner can obtain a small loan from the bank.
<b>Type of Ownership</b>	Own outright Own with debt (mortgage or other)
<b>Additional comments on ownership</b>	Generally, this housing type is occupied by middle class individuals who obtain a mortgage for a period of several years.

<b>Is earthquake insurance for this construction type typically available?</b>	Yes
<b>What does earthquake insurance typically cover/cost</b>	<p>Until 2003 Boumerdes earthquake, for seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage was unavailable. In general, strengthening of buildings by incorporating seismic features is not common. Some government-financed retrofit projects were recently completed for some strategic buildings in the capital city Algiers. The government also finances strengthening of damaged public buildings following an earthquake. As there was no insurance before Boumerdes event, the owners of individual housing have been given symbolic aid from the government if damage is slight. If the damage was heavy, repairing and strengthening was financed by the government as was the case after the 2003 Boumerdes earthquake. Earthquake insurance for all construction types is available since 2004 This insurance, known as CATNAT, was set up following the Boumerdes earthquake by the group of insurance companies. The insurance premium is assessed, for the moment, only on the seismic zone, the surface and the height of the construction. Since the beginning of 2013, a working group was set up to reflect on the parameters to be taken into account for the evaluation of the premium.</p>
<b>Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?</b>	No
<b>Additional comments on premium discounts</b>	
<b>Additional comments section 4</b>	It is not common that owners purchase earthquake insurance. Until now, CATNAT insurance covers only 6-10% of the total housing.

## Earthquakes

### Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter

1980	El Asnam
1989	Tipaza
1999	Ain Temouchent
2003	Zemmouri (Boumerdes)

## Past Earthquakes

<p><b>Damage patterns observed in past earthquakes for this construction type</b></p>	<p>The moderate Tipaza (1989) and Ain Temouchent (1999) earthquakes have severely affected concrete frame housing construction designed without seismic features. The typical patterns of damage included collapse of some houses, failure of short columns at the ground floor level and below (vide sanitaire), development of plastic hinges in the ground floor, axial crushing of concrete in the columns and shear damage to the column-beam joints. During the 1980 El Asnam earthquake, two- and three-level stone masonry that had been strengthened after the El Asnam (Orleanville) earthquake of September 1954 performed well. The 2003 Boumerdes earthquake (Magnitude 6.8) severely affected concrete frame housing designed without seismic features. Generally, a significant number of RC buildings built after the 1980 were damaged and this specific building type was the most affected by the earthquakes in Algeria.</p>
<p><b>Additional comments on earthquake damage patterns</b></p>	<p>Walls: Out of plane collapse, Classical X shear cracking. Frames: Buckling of the storey. Roof/Floor: Total/partial collapse. Connections: Excessive rotations, shear failure of the welds, unsitting.</p>

## Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than  $\frac{1}{2}$  of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than  $\frac{1}{3}$  of the distance between the adjacent cross walls; For precast concrete wall structures: less than  $\frac{3}{4}$  of the length of a perimeter wall.

<b>Structural/Architectural Feature</b>	<b>Statement</b>	<b>Seismic Resistance</b>
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE

Wall Proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	N/A
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doveled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

## Building Irregularities

	Reinforced concrete frame construction, built after the first seismic code was issued in 1981, was (in
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<b>Additional comments on structural and architectural features for seismic resistance</b>	spite of the existence of the code) designed for gravity loads only and without seismic features. Currently, a major problem related to this type of construction results from the lack of quality construction materials and insufficient controls during construction.
<b>Vertical irregularities typically found in this construction type</b>	Torsion eccentricityOther
<b>Horizontal irregularities typically found in this construction type</b>	Soft/weak storyOther
<b>Seismic deficiency in walls</b>	A conventional building of large panel concrete construction or brick masonryconstruction: poor quality of panel joints and inadequate masonry strength.
<b>Earthquake-resilient features in walls</b>	Use of bands ties the walls together and ensures effective load transfer under earthquake loading
<b>Seismic deficiency in frames</b>	Lack of seismic resistance, as the structural elements are designed for gravity load only. The main deficiencies include: - column cross-section not sufficient to provide earthquake resistance. - absence of stirrups in beam-column joints. - lack of infilled masonry walls at the ground floor, thus creating a soft storey effect (see Fig. 10 and 11) - excessively large stirrup spacing in columns. - poor quality of materials and workmanship.Partial or total collapse of the building due essentially to excessive displacement (P-delta effect) at the ground floor level. The characteristic damage patterns include: failure of the top portion of columns at the ground floor level, development of plastic hinges in the columns (ground floor), crushing of columns due to axial compression, shear failure in column-beam joints.
<b>Earthquake-resilient features in frame</b>	In some cases, vertical reinforcement in RC frame houses is sufficient and contributes to increase the earthquake resistance under earthquake loading.
<b>Seismic deficiency in roof and floors</b>	#NAME?
<b>Earthquake resilient features in roof and floors</b>	#NAME?
<b>Seismic deficiency in foundation</b>	Generally, no damage to foundation

**Earthquake-resilient features in foundation**

The foundation ground beams connecting the footings contribute to their good seismic behavior.

**Seismic Vulnerability Rating**

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines](#)

	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class	-	-				



**Seismic deficiencies: weak beam-column joint (2003 Boumerdes earthquake)**



**Seismic deficiencies - very poor quality of concrete (2003 Boumerdes earthquake)**



**Typical earthquake damage: building collapse due to the soft storey effect (2003 Boumerdes)**



**Typical earthquake damage: soft storey collapse (2003 Boumerdes earthquake)**

*earthquake)*



***Damaged weak and flexible RC moment frame buiding system by 2003 Boumerdes earthquake***



***Damaged RC moment frame buiding by 2003 Boumerdes earthquake***



***RC moment frame buiding. Weak and flexible first story damaged by 2003 Boumerdes earthquake.***



***Typical RC moment frame buiding floor. Hollow concrete blocks supported by small precast beams and a 40-50 mm thick cast-in-place slab***

## **Retrofit Information**

### **Description of Seismic Strengthening Provisions**

<b>Structural Deficiency</b>	<b>Seismic Strengthening</b>
Slight crack	Local repair with injection
Columns and beams: heavy	Local repair by providing reinforced concrete

cracks, development of plastic hinges, axial compression crushing	jacketing; new structural elements added to increase the seismic resistance (shear walls or bracing)
Column design requirements (RPA99), see Fig.14	Dimensions ( $b_1 =$ width, $h_1 =$ depth): Min ( $b_1, h_1$ ) > 25 cm (seismic zones I and IIa); Min ( $b_1, h_1$ ) > 30 cm (seismic zones IIb and III); Min ( $b_1, h_1$ ) > $h_e/20$ ( $h_e =$ story height); $b_1/h_1 < 4$ . Minimum reinforcement ratio (longitudinal bars): 0.8% (zone IIa); 0.9% (zone IIb and III); Transverse reinforcement (ties) should also be provided.
Beam design requirements (RPA99), see Fig.14	Dimensions ( $b =$ width, $h =$ depth): $b > 20$ cm, $h > 30$ cm, $h/b < 4.0$ , $b_{max} < 1.5 h + b_1$ . Reinforcement: the minimum longitudinal reinforcement ratio is 0.5%
Joint requirements, see Fig.14	Transverse reinforcement (ties) should be continuous through the joints.

**Additional comments on seismic strengthening provisions**

Columns and beams: heavy cracks, plastic hinges, axial compression crushing Column design requirements (RPA99 version 2003), see Fig.14 The most commonly used method for strengthening reinforced concrete frame buildings is reinforced concrete jacketing. The addition of new structural elements (such as shear walls or bracings) is rarely used. Construction of new shear walls is a common retrofit method for larger reinforced concrete frame buildings despite its high cost. (For example, this was done after the 1999 Ain Temouchent earthquake.) The addition of shear walls results in the increased lateral strength and stiffness of a building. As a result, seismic performance increases significantly as well. The walls are laid in a symmetrical manner to reduce torsional response. The bracing systems are not used very often.

**Has seismic strengthening described in the above table been performed?**

The first experience related to repairing and strengthening damaged buildings in Algeria was following the 1980 El Asnam earthquake (M 7.3). Also, some buildings strengthened after the previous (1954) El Asnam earthquake performed very well (without damage) in the 1980 Asnam earthquake. The methods described in Section 10.1 were applied. Other projects to strengthen damaged public buildings were undertaken after recent earthquakes such as the 1999 Ain Temouchent earthquake. The strengthening of buildings after the 2003 Boumerdes eq. has started but is not yet finished as of this writing (January 2004). The related seismic strengthening studies

were entrusted to local engineering and design offices. The damaged elements were repaired with injection or with reinforced concrete jacketing. New structural elements (shear walls) were added only to the damaged structures of existing public buildings to increase their lateral load resistance.

**Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?**

This work was done as the repair following the earthquake. In a few cases it was done specifically as part of a mitigation effort for a few undamaged strategic buildings in Algiers.

**Was the construction inspected in the same manner as new construction?**

The damaged construction is inspected in the same manner as the new construction.

**Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?**

Owners build their own homes, and architects and engineers are never, or rarely ever, involved. In the aftermath of the 2003 Boumerdes earthquake, the repairing and strengthening operation was financed by the government and performed by contractors and developers. In this case both the architects and engineers were involved.

**What has been the performance of retrofitted buildings of this type in subsequent earthquakes?**

Construction which was strengthened following the earthquakes which struck northern Algeria (Tipaza, 1989 and Ain Temouchent, 1999) was not affected by other earthquakes. The 2003 Boumerdes earthquake did not affect those areas so it is not yet known how retrofitted buildings will perform in future earthquakes. However, some vulnerability studies of the strengthened housing were completed, which concluded that strengthened buildings should perform well in future moderate earthquakes.

**Additional comments section 6**



***Seismic strengthening techniques:  
jacketing of columns and  
construction of new shear walls in  
the two directions (after the  
2003Boumerdes earthquake)***

## **References**

El Asnam earthquake report, 1981CTC  
Organisme de Controle Technique de la  
Construction 1981

Tipaza earthquake report, 1990CGS  
Centre National de Recherche Appliquee en Genie  
Parasismique 1990

Catalogue des Methodes de Reparation et de Renforcement des OuvragesCGS  
Centre National de Recherche Appliquee en Genie Parasismique 1992

Boumerdes earthquake report, 2003d'Alger,W.

Boumerdes earthquake report, 2003de Boumerdes,W.

Centre National de Recherche Appliquee en Genie Parasismique (Regles Parasismiques  
Algerienes (RPA99)Alger, Algerie 2000

Conception et Calcul des structures en beton arme CBA93CGS  
Centre National de Recherche Appliquee en Genie Parasismique 1994

Guide de Construction Parasismique des Maisons Individuelles et Batiments  
AssimilesCGS  
Centre National de Recherche Appliquee en Genie Parasismique 1995

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